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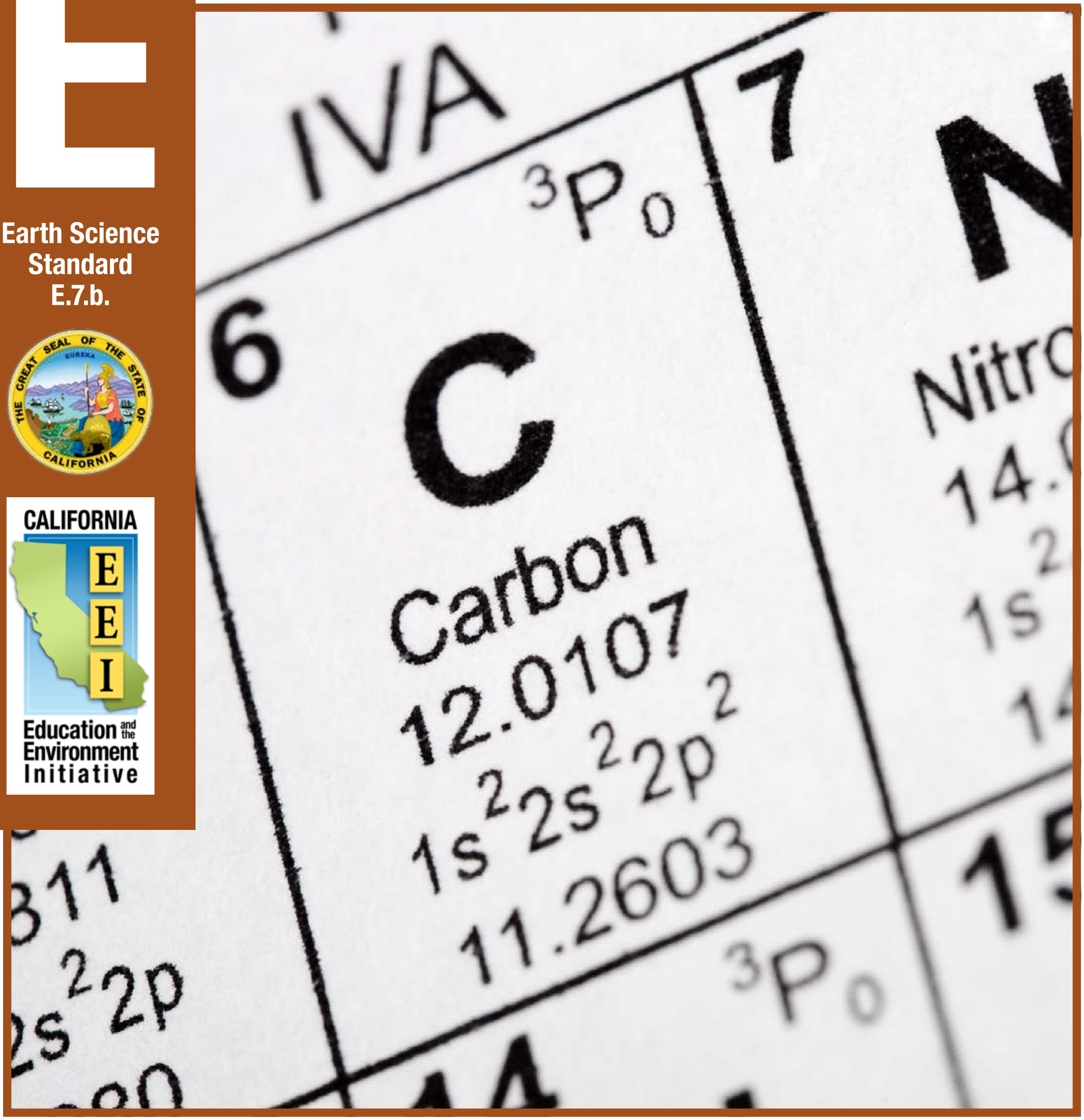
Earth Science Standard E.7.b.

CALIFORNIA Education and the Environment Initiative

Teacher's Masters

California Education and the Environment Initiative



The Life and Times of Carbon

California Education and the Environment Initiative

Approved by the California State Board of Education, 2010

The Education and the Environment Initiative Curriculum is a cooperative endeavor of the following entities:

California Environmental Protection Agency

California Natural Resources Agency

California State Board of Education

California Department of Education

Department of Resources Recycling and Recovery (CalRecycle)

Key Partners:

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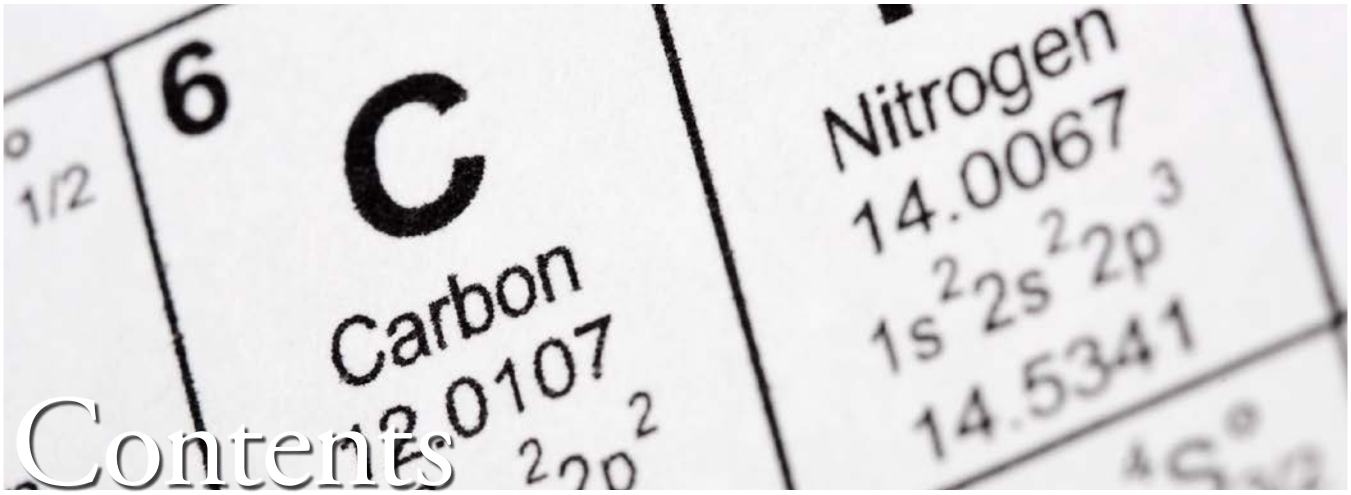


Contents

Lesson 1 Carbon: The Building Block of Life

None required for this lesson.

Lesson 2 We Live in a Carbon-ated World

Lesson 3 Carbon Cycling: Waste Not, Want Not

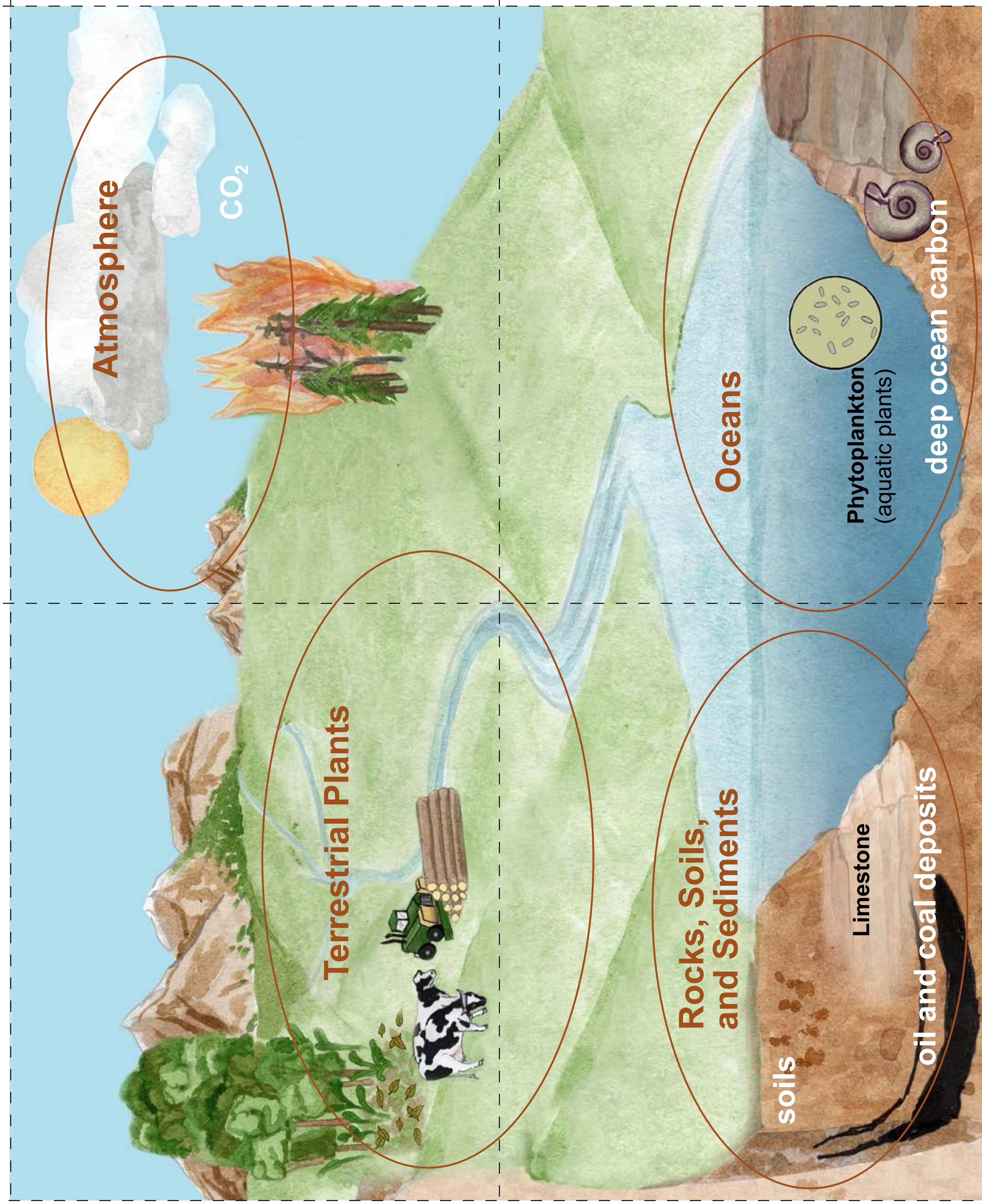
Lesson 4 It Started with Fire

None required for this lesson.

Lesson 5 Biofuels in the News

None required for this lesson.

Assessments


Atmosphere
CO_2
Oceans
Phytoplankton
(aquatic plants)
deep ocean carbon
Terrestrial Plants
Rocks, Soils,
and Sediments
Limestone
soils
oil and coal deposits

Oceans

Carbon dioxide (CO_2) from the atmosphere is mixed into the top surface of oceans by waves and wind. This CO_2 is taken up by small aquatic plants that live near the ocean's surface called "phytoplankton." They take up CO_2 and convert it into "plant" carbon matter. Using satellite imagery, scientists have measured huge algae "blooms" that show how carbon is distributed throughout the ocean. Overall, oceans are Earth's second largest carbon reservoir, holding 38,000–40,000 billion metric tons of carbon. Most of this is sunk down to the deep ocean.

Aquatic animal bodies are made up of various carbon compounds. Some are able to convert carbon into calcium carbonate to form protective shells.

When aquatic organisms die, they are consumed and decomposed by microbes, and much of this matter sinks to the ocean bottom. Layers upon layers of carbon-containing seashells become compressed under the weight of the ocean and, in time, become the sedimentary rock we call limestone or marble.

Atmosphere

Earth's atmospheric gases originated during a very active volcanic period billions of years ago. Volcanoes released carbon dioxide (CO_2), water vapor, and other gases into the atmosphere. Early plants were algae. Algae took up gaseous CO_2 and, with sunlight, water, and the process of photosynthesis, produced oxygen and plant matter. As more complex plants and animals evolved, atmospheric CO_2 levels became fairly well-balanced by the natural processes of photosynthesis, respiration, and decomposition. Today's atmosphere holds 766 billion metric tons of carbon.

Atmospheric CO_2 levels have gone up and down throughout Earth's history. Fossils tell us that CO_2 levels have been as low as 180 parts per million (ppm, a percentage of all atmospheric gases). Today they are at 384 ppm. CO_2 is a greenhouse gas that regulates Earth's temperature. High levels of greenhouse gases cause Earth to be warmer, while low levels cause Earth to be cooler. Other carbon-based gases found in the atmosphere include, methane (CH_4) and carbon monoxide (CO).

Rocks, Soils, and Sediments

The world's soils hold 1100 to 1600 billion metric tons of carbon. This is more than twice the carbon stored by living vegetation or in the atmosphere. Yet, this figure is small compared to marine sediments and sedimentary rocks: they hold between 66,000,000–100,000,000 billion metric tons of carbon! Fossil fuels were formed 354 to 290 billion years ago when plants became buried under sediments and oceans. Fossil fuel deposits hold another 4000 billion metric tons.

Soil carbon comes mostly from the decomposition of plants by microbes. "Leaf litter" accumulates year after year and results in much of the carbon becoming buried and trapped in lower layers of soil.

Forests produce a lot of leaf litter, resulting in soils high in carbon. Tropical forests grow year-round and are mega-warehouses of carbon.

At the bottom of wetlands there is little or no oxygen. Here, the decomposition process is very slow. Wetlands, peat bogs, and permafrost (wet frozen lands) store tremendous amounts of carbon.

Terrestrial Plants

Plants take up carbon dioxide from the atmosphere during photosynthesis. Carbon is stored by plants in leaves, stems, roots, and woody material, even roots. Because of their size, trees are able to store a large amount of carbon as "wood." Forests are often called "the lungs of the world" because they convert so much carbon dioxide gas into oxygen. Terrestrial (land) forests of North and South America are massive carbon reservoirs.

Trees are definitely the largest forms of plants, but all plants store carbon, from small aquatic algae and alpine moss-like lichen to grasses, shrubs, and cactus. In total, the terrestrial plant reservoir stores 540–610 billion metric tons of carbon.

Animals depend on the oxygen created by plants, and animals eat plants or other animals. This "consumption" moves carbon up the food chain and throughout the food web.

Even though animals (including people) store carbon in various carbohydrate compounds within our bodies, the amount is very small compared to that stored by vegetation. Therefore, scientists do not consider "animals" as a carbon reservoir.

Carbon Flow Game Instructions

1. Center the game board between all players; set the **Carbon Flow Scenario Cards** facedown to one side.
2. Arrange the carbon game pieces (poker chips) according to the following guide:
   - The red chips represent fossil fuels. Place all three in the "Rocks, Soils, and Sediments" reservoir.
   - Add 11 more poker chips to "Rocks, Soils, and Sediments" reservoir.
   - Place six chips in the "Ocean" reservoir.
   - Place two chips in the "Atmosphere" reservoir.
   - Place two chips in the "Terrestrial Plants" reservoir.
   - Select someone from your group to start the game and then take turns clockwise.
3. During their turn, players draw one **Carbon Flow Scenario Card** from the stack, read it aloud, and move the carbon game pieces to show how carbon moves from one reservoir to another during different processes. (*Note: There may be situations where the carbon does not move.*)
4. During each turn, players record how they believe carbon moves on their individual **Carbon Flow Observation Log**.
5. After all cards have been drawn, leave the game pieces on the board in place to refer to during the group discussion that follows.

Feel the Burn

Every year, fires burn about 2 million square miles of Earth's land surface and release more than 1 billion tons of carbon into the atmosphere in the form of carbon dioxide. In 2006, a record-setting number of 96,385 wildfires destroyed nearly 10 million acres of forest in the United States alone.

Scientists estimate that for every acre burned, between 30 and 77 metric tons of carbon is released to the atmosphere. Most is in the form of CO_2, but carbon monoxide and methane are also released.

Large forests are able to store massive amounts of CO_2. Once burned, the lost forests and vegetation are not taking up CO_2 through photosynthesis. After a fire, new vegetation grows on the burned land. Even though new vegetation takes up CO_2 and stores carbon, the new grasses, shrubs, and small trees are not as effective at taking up CO_2 as larger trees.

Fires result in ….
(Move one carbon piece to a new reservoir.)

Seeing the Forest Through the Trees

The process of photosynthesis takes up carbon dioxide from the atmosphere and stores the carbon as plant material. Because of the large amount of carbon stored as wood, forests are one of the largest reservoirs of carbon on Earth.

There are currently more forests in the United States today than there were 100 years ago. During early colonization of North America, people cut down huge amounts of forests to grow crops and for wood to build early cities and homes. Over the past 100 years, North American forests have regrown. Some farming practices have become more efficient and require less land. Appropriate forest management based on sustained yields can also help. In the past decade, forests have been getting larger in Europe and China, as well. In Europe, forests are increasing by 32 million acres each year, an area about the size of Alabama. In China, forests are increasing by 4½ million acres each year, an area about the size of Delaware.

More forests results in …
(Move one carbon piece to a new reservoir.)

Our Changing Landscape

There are 6.8 billion people on the planet today and, by 2030, this number is expected to be 9 billion. Rapid human population growth, combined with increasing resource consumption, has resulted in the widespread transformation of Earth's land surface. We call this "land use change."

People change the land: we build homes, cities, and roads. We clear land to grow crops and manage livestock. Worldwide, people have cleared lands about the size of South America just to grow crops. We use even more land for ranching, to graze livestock, such as cattle, goats and sheep.

Recently, the largest land use changes have occurred in developing nations, such as South America and Malaysia. People are burning or cutting tropical forests to grow food crops or to raise cattle. In recent years, people have turned to growing crops to produce ethanol, which can be made from corn, soybeans, sugar cane, and other food crops. There has been research suggesting that it might be possible to store carbon in farm and grasslands by moving to "no-till agriculture" (which reduces soil disturbance).

Both burning trees and disturbing the soil release carbon into the atmosphere. A second carbon penalty is that once a tree is cut, it can no longer take up atmospheric carbon.

Land use changes result in...
(Move two carbon pieces to new reservoirs.)

Fossil Fuels "Old-Growth" Carbon

Fossil fuels were formed 354–290 million years ago during the Carboniferous period, when dead plants became buried and compressed. Before they died, these plants harnessed the Sun's energy and stored it as plant material. The carbon from these buried plants became concentrated in "fossil" fuels, such as coal, petroleum, and natural gas.

Like a ship of gold lost at sea, this buried treasure has not been part of the global carbon cycle for hundreds of millions of years. In fact, until people began extracting fossil fuels, this carbon was "out of the loop" with regard to the global carbon cycle.

Now we burn fossil fuels to use their stored energy to power our cars, electric power plants, and more. One of the waste products of combustion is the carbon dioxide that comes out our tailpipes and chimneys.

The ocean absorbs a lot of this "extra" carbon.
Where does the rest go?
(Move two red carbon pieces to new reservoirs.)

Pumping Carbon

The ocean is the second largest carbon reservoir on Earth. In fact, with regard to the global carbon cycle, the ocean is taking in *much* more carbon than it releases. This is partly because it covers three-quarters of Earth's surface, but also because it is so deep and is teeming with life.

It is the smallest life forms that are the real work horses. These include tiny organisms are called phytoplankton: microscopic algae that drift near the ocean's surface. Phytoplankton take up CO_2 and, through photosynthesis, convert it into biomass and oxygen. Phytoplankton play an important role in the biological pump that takes atmospheric carbon and sinks it into the deep ocean sediments.

One idea scientists have is to "fertilize" the ocean with nutrients that would cause more phytoplankton to grow. More phytoplankton will take up more atmospheric CO_2, but researchers warn that this plan might backfire: scientists believe that increased phytoplankton pumping CO_2 to the deep ocean triggered past ice ages. However, a bigger concern today is that the pumping will not work and will negatively affect ocean biology. For now, it might be better not to mess with nature's biological pump.

The natural biological pump results in…
(Move one carbon piece to new reservoir.)

How Permanent Is Permafrost?

Permafrost is land that is frozen for at least two years in a row. Permafrost is common on land near Earth's poles, in northern regions and on alpine mountains. Like the name suggests, this ground contains frozen water.

Some plants have adapted to grow in permafrost during the short summers. When these slow-growing plants die, they are quickly frozen and buried. Winter comes quickly in permafrost regions, so the plant material does not decompose very much. In other words, the carbon stored within the plant fibers is trapped beneath a frozen blanket. Permafrost soil is full of carbon dioxide and methane (CH_4)—another form of carbon.

It is the frosty conditions that keep carbon locked in permafrost. When permafrost thaws, it releases carbon to the atmosphere. The past decade has seen record summer heat, and scientists predict the warming trend to continue.

Thawing permafrost will result in …
(Move one carbon piece to a new reservoir.)

A Wetland "Wasteland?"

Wetlands are areas that are underwater for at least some part of the year. Wetlands are filled with plants that have adapted to grow well in wet soil. When the vegetation dies, some will decay, releasing carbon dioxide and another carbon compound—methane (CH_4)—to the atmosphere. But the vegetation can build up as sediment, forming a reservoir of carbon.

Wetlands used to be thought of as wasted land, and they were drained and filled for development. Between the 1780s and 1980s, 60 acres of wetlands were lost every hour across the country. In California alone, less than 9% of the state's historic wetlands remain. Today, most California wetlands are protected from further development.

For saltwater wetlands, such as salt marshes, legal protection is not enough. Rising sea levels can flood shoreline vegetation. Even though salt marsh plants are adapted to salt water, most cannot survive under constantly flooded conditions. Shoreline vegetation acts like a shock absorber against waves. When shoreline vegetation is lost, erosion is more prevalent. Lost wetlands decrease photosynthesis and expose sediments and soils to erosion.

Wetland loss results in…
(Move one carbon piece to a new reservoir.)

Cement, Our Modern Building Block

Concrete is a building material which is made from a mixture of cement, clay, gravel, sand, and water. Cured concrete is like stone, and so buildings, bridges, and roads are expected to last a long time.

Cement is made from lime, which is made from limestone. Remember that limestone is sedimentary rock formed from the fossilized calcium carbonate remains of marine organisms. To make lime out of limestone, concrete factories heat limestone to very high temperatures. In the process of converting calcium carbonate into lime, carbon dioxide is given off and released to the atmosphere.

Overall, the cement industry produces 5% of global human-made CO_2 emissions. This comes to about 900 kg of CO_2 released to the atmosphere for every 1,000 kg of concrete produced.

The top three annual producers of concrete are China with 704 million metric tons, India with 100 million metric tons, and the United States with 91 million metric tons. This translates into about half the world's total production of concrete.

Producing concrete results in…
(Move one carbon piece to a new reservoir.)

Made of Wood Is Good

Wood is a reservoir for carbon whether is it alive or dead. This means that wood used for building materials and furniture is still storing some of the carbon that was in the original tree (about one-third of the original tree is able to be converted into furniture). In fact, dry wood is about 50% carbon. To make paper products, woody fibers are partially broken down to a pulp. Paper stores much less carbon than wood that is cut for use in construction or to make furniture.

Forests can be managed to protect them as a valuable ecosystem, but they can also be managed to store as much carbon as possible. Trees in their middle years convert more carbon dioxide than when they are small saplings or slow-growing, large, old growth trees.

Forest managers believe that we can manage the amount of carbon dioxide that is in the atmosphere by maintaining and managing trees.

Cutting trees for use in construction, furniture, and other wood products results in…
(Move one carbon piece to a new reservoir.)

Name: ______________________________

Instructions: Select the best answer and circle the correct letter. (1 point each)

1. Which of the following is/are true?
   a. Human-made plastics and nylons do not contain carbon.
   b. Only living organisms contain carbon.
   c. All living and many nonliving materials contain carbon.
   d. All of the above.

2. Which of the following statement(s) is true?
   a. Biotic matter contains carbon, but abiotic matter does not.
   b. We can still have life on Earth without carbon.
   c. Plants contain carbon compounds called "carbohydrates" but animals (including people) do not.
   d. Carbon is an element that forms millions of compounds that make life possible.

3. Photosynthesis is the___________________________.
   a. uptake of oxygen and the release of carbon dioxide by animals
   b. uptake of oxygen and the release of carbon dioxide by plants
   c. uptake of carbon dioxide and the release of oxygen by plants
   d. uptake of carbon dioxide and the release of oxygen by animals

4. Which natural process breaks down dead matter into its chemical and mineral components that can be used by other organisms for nutrients?
   a. photosynthesis
   b. respiration
   c. decomposition
   d. greenhouse effect

5. Carbon dioxide is used in natural processes within which of the following carbon reservoirs?
   a. terrestrial plants
   b. the atmosphere
   c. rocks
   d. a, b, and c

6. Which of the following are examples of carbon reservoirs?
   a. sunlight
   b. maple tree
   c. limestone floor tiles
   d. both b and c

Name: ___________________________________

7. The global carbon cycle involves which factor(s)?
   a. the flow of carbon matter and energy from one reservoir to another
   b. the natural processes of photosynthesis and respiration
   c. a holding place for carbon, including the ocean, terrestrial living organisms, soils, sediments, and atmosphere
   d. All of the above.

8. A carbon "sink" is best described as ____________________________.
   a. a reservoir that readily releases carbon to another reservoir
   b. a carbon reservoir that takes up more carbon than it is releasing or emitting
   c. something that causes carbon to leak out to the atmosphere
   d. a carbon reservoir that is releasing more carbon than it is taking in

9. When the amount of carbon within a reservoir changes because of processes that release or take up carbon in another reservoir, it is called a ___________________________.
   a. carbon flow
   b. carbon neutral
   c. saving energy
   d. carbon footprint

10. Which ocean organism is responsible for taking up atmospheric carbon dioxide?
    a. fish
    b. phytoplankton
    c. switchgrass
    d. whales

11. Which of the following are examples of human activities that can alter the global carbon cycle?
    a. planting forests
    b. cutting down forests
    c. plowing up soil during farming
    d. All of the above.

12. Carbon moves from one reservoir to another _____________________________.
    a. during a forest fire
    b. when we produce cement
    c. when we dig a hole in the ground to make a swimming pool
    d. both a and c

Name: ________________________________

13. Select all statements that are correct:
    a. Biofuels are made from plant material and include wood, corn, switchgrass, and plant waste.
    b. All biofuels are alike in the amount of carbon they emit during their production or use.
    c. All biofuels are alike in regard to the amount of carbon they emit during production or use.
    d. Both a and c.

14. Food shortages are best represented as___________________________.
    a. environmental and economic trade-offs that can result when we use corn ethanol
    b. social and economic trade-offs that can result when we use corn ethanol
    c. social and political trade-offs that can result when we use corn ethanol
    d. political and environmental trade-offs that can result when we use corn ethanol

15. The term “carbon footprint” refers to __________________________.
    a. only the amount of energy used in transportation
    b. the excess carbon dioxide that is emitted to the atmosphere when we use carbon-based resources
    c. only biofuels that are carbon neutral
    d. the amount of carbon that we consume to survive

Instructions: Match each definition with its correct term. (1 point each)

____ 16. The time period (354–290 million years ago) when undecayed vegetation became buried and formed fossil fuels.	a. Carbon cycle
____ 17. The movement of carbon, in its many forms, between the atmosphere, ocean, living organisms, and land and rocks.	b. Carboniferous period
____ 18. The chemical or mechanical breakdown of rocks exposed to the weather (for example, wind and rain).	c. Greenhouse effect
____ 19. The effect of greenhouse gases absorbing outgoing infrared radiation, raising a system’s temperature.	d. Photosynthesis
____ 20. The process by which plants and algae convert light energy into chemical energy stored in carbohydrates.	e. Reservoir
____ 21. A holding place for carbon, including the ocean, terrestrial living organisms, soils, rocks, sediments, and atmosphere.	f. Weathering

Name: ________________________________

Instructions: Complete the tasks below in the space provided.

22. Select one of the four major carbon reservoirs and describe one major function carbon serves while in that reservoir. (2 points)

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23. Using the reservoir you identified in question #22, briefly describe one natural process and one human activity involved in moving carbon to or from this reservoir. (2 points)

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24. Describe how people depend on and benefit from the carbon cycle. (2 points)

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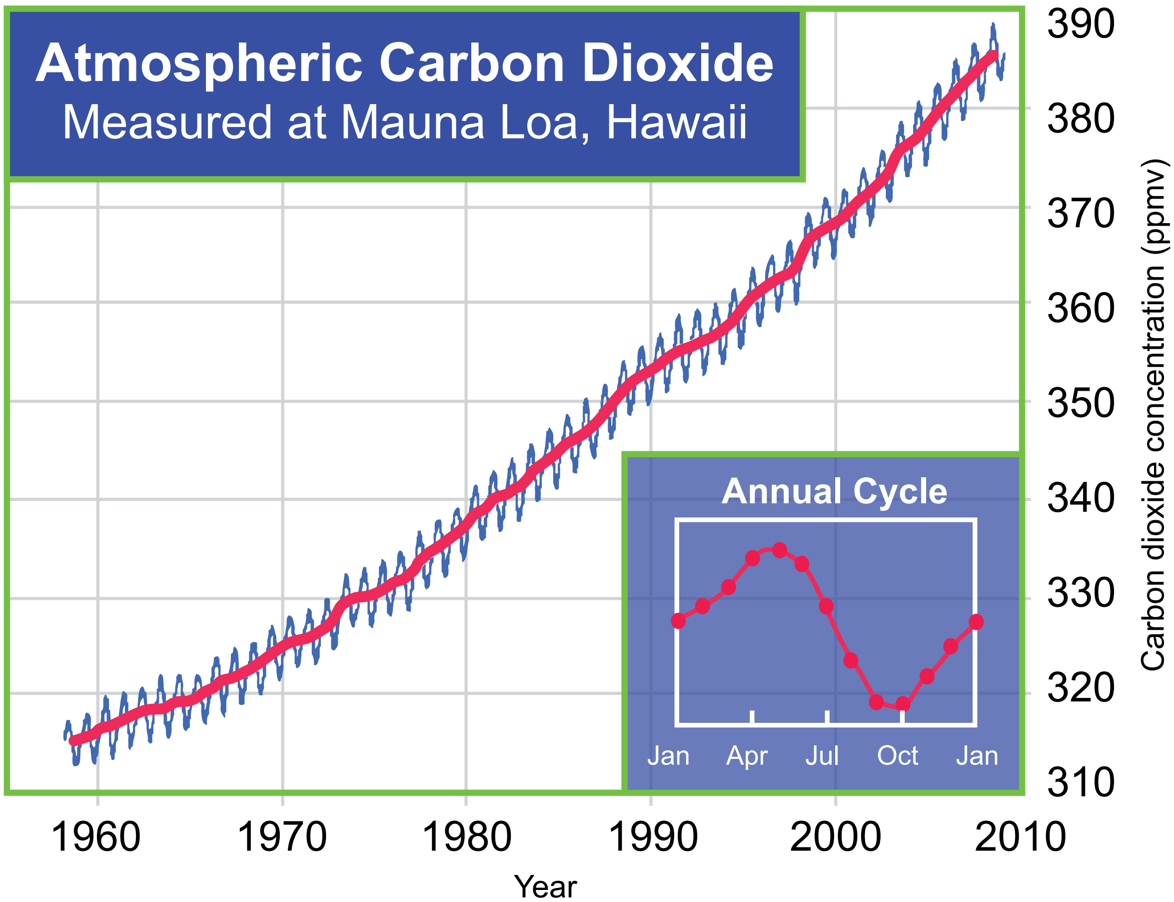
Name: ______________________________

Instructions: Examine the graph below, and answer questions 25 and 26 in the spaces provided.



Graph 1. Changes in atmospheric carbon dioxide from 1958 to present.
Source: R. F. Keeling, S. C. Piper, A. F. Bollenbacher, and S. J. Walker, Carbon Dioxide Research Group, Scripps Institution of Oceanography, La Jolla, California, February 2009

25. Describe what the “Annual Cycle” is and why the data move in a zigzag pattern. (5 points)

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Name: ______________________________

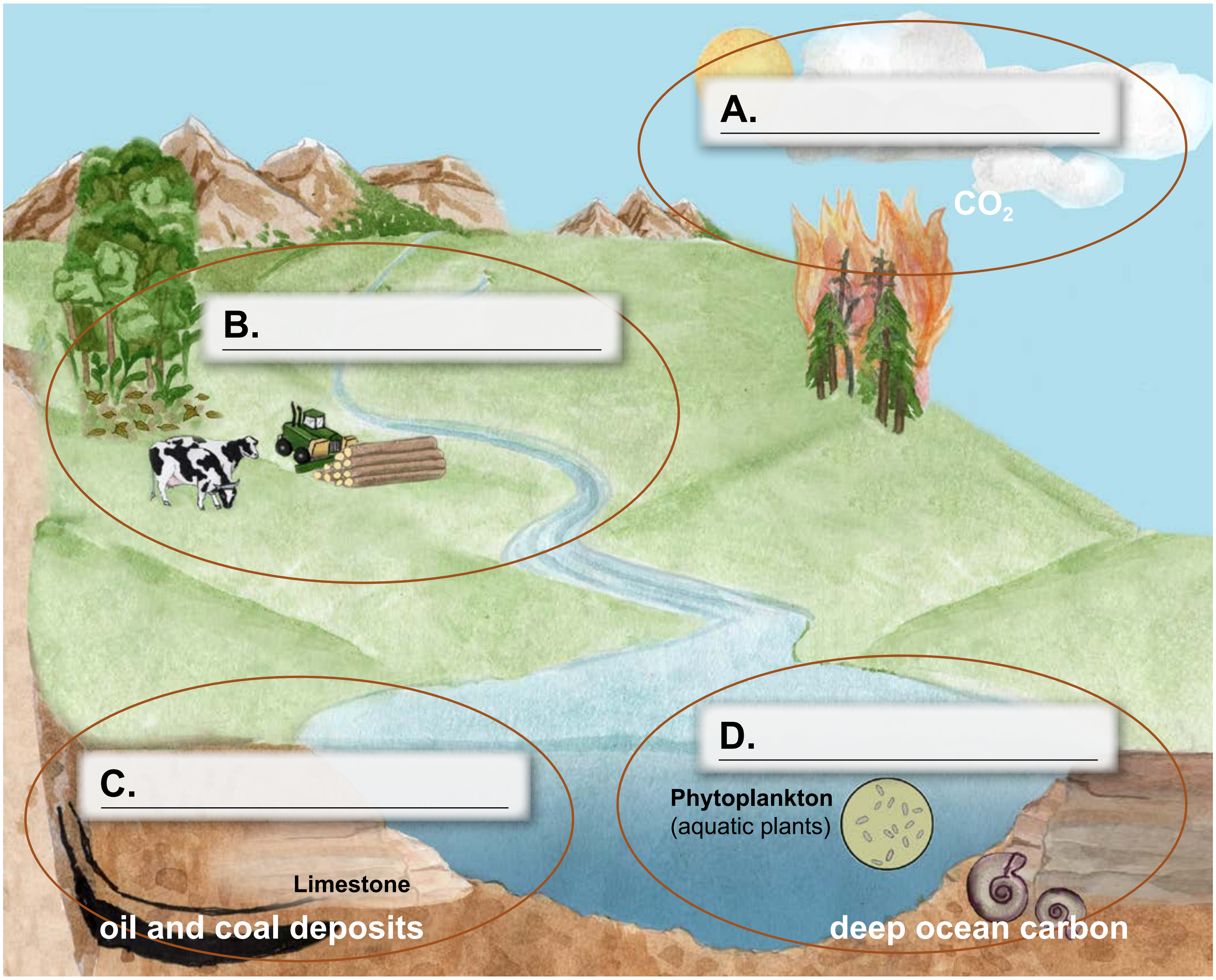
26. Explain what is happening to the concentration of carbon dioxide over time, and what scientists believe is causing carbon dioxide levels to change since 1958. Include an explanation of where this "extra" carbon dioxide was before it was emitted to the atmosphere. (4 points)

27. We reviewed four major decision-making factors in class: social, economic, political, and environmental. Select one and briefly describe how our decisions about carbon-based energy can change over time. Include an example that justifies your answer. (4 points)

Name: ______________________________

Instructions: Complete the tasks below.

1. Label the four carbon reservoirs in the illustration below and draw arrows showing the flow of carbon matter and energy as it moves in the global carbon cycle. (3 points each, 12 points total)



Name: ______________________________

Instructions: Complete the tasks below.

2. You are a student at a university studying carbon energy sources that you hope will be the answer to people's transportation and energy needs. Based on what you know about the carbon cycle, select a carbon reservoir that you plan to research. In the space provided, describe your idea for developing a carbon energy source or an improved carbon sink. Write a short essay that includes each of the following components in your response.
   - Explain how the carbon energy and matter flows naturally to this reservoir, and what happens to it once it gets there (how it is used in nature; how natural systems depend on it being there). (10 points)
   - Explain how your proposed study will benefit people. (5 points)
   - Justify why this particular carbon energy "source" makes sense with regard to the entire global carbon cycle. How does it fit in with the carbon cycle and why is your idea a better alternative than current efforts? In other words, describe the trade-offs related to using the energy source. (10 points)
   - Describe its beneficial and detrimental outcomes. (4 points)

Name: ______________________________

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